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ORIGINAL PAPER

Building a national wetland inventory: a review and roadmap to move forward

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Abstract An inventory is internationally recognised as a key tool for informing policy, management and conservation of wetlands. Despite national, state and territory initiatives a comprehensive Australian wetland inventory still does not exist. The primary data requirements for a national wetland inventory are standardised mapping of wetland extent and attribution of typology. Some Australian jurisdictions have ongoing and regularly updated wetland mapping programs that could be consistent with a national inventory framework, whereas others have outdated or scattered information and data. Data requirements for wetland inventories have been reviewed previously, but there have been several recent improvements in technology and available information since those reviews were completed. The focus of this paper is to update previous reviews by outlining the recent opportunities that have emerged, and present a roadmap to support implementation of a jurisdictional wetland inventory program. We applied the process to the Lachlan River catchment in New South Wales, demonstrating the value and relevancy of the roadmap for inventory development. The need for standardised jurisdictional wetland inventories is the first step to their integration into a national wetland inventory. The roadmap and frameworks developed here can guide the development of other programs to overcome impediments and support development of a national wetland inventory. This tool would ultimately support the maintenance, protection and restoration of wetlands at a national level.

Keywords Wetlands · Wetland inventory · Environmental management · Lachlan River catchment · Australia

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Introduction

Wetland ecosystems are widely recognised for contributing forty percent of global annual renewable ecosystem services while covering only 6% of the globe (Zedler and Kercher 2005; Junk et al. 2013). Despite their importance, it is estimated that 30–90%

of the world's wetlands (dependent on region) have been lost due to human pressures (Prahalad and Kriwoken 2010; Junk et al. 2013). A wetland inventory program that is based on mapping and classification (Finlayson and van der Valk 1995; Rebelo et al. 2009) is widely acknowledged as an essential tool for managing in order to maintain wetland ecological character and protect the critical services that wetlands provide globally (Davidson and Finlayson 2007).

National wetland inventories date back at least to the early 1950s, with many countries in Europe and North America having produced inventories of their wetland resources (Scott and Jones 1995). In 1995, nine European countries had reported wetland inventories (Hughes 1995) and 27 wetland inventory sources were included in the Western European dataset (Stevenson and Frazier 1999). A subsequent review noted, however, that there was no 'comprehensive' inventory of all wetlands completed for any European country (Nivet and Frazier 2001). In 2017, 49 European countries had listed 1088 Ramsar sites (Ramsar 2017).

The most advanced and ongoing wetland inventory program continues to be the National Wetland Inventory (NWI) of the United States of America. It began in 1974 and has been operational since 1979. The program quickly identified that the first kind of information required was wetland maps (Wilen and Bates 1995). Over the past (nearly) 40 years, the mapping has been continually updated (Tiner 2005; Vanderhoof et al. 2016). Additional products (such as statistical reports of wetland trends, lists of hydric soils, a national list of wetland plant species, a wetland values database and wetland reports for all states) have also informed the development of Federal programs and policies (Wilen and Bates 1995).

Despite these international precedents and identified need (Kingsford et al. 2005), a comprehensive Australian wetland inventory still does not exist. In 1993, the first edition of a listing of Australia's important wetlands was published (Directory of Important Wetlands in Australia: DIWA, Environment Australia 2001). The latest online version (known as the Australian Wetlands Database) now holds descriptions of more than 900 DIWA wetlands. The DIWA database is not comprehensive, however, and covers only wetlands that are considered nationally important according to specific criteria (Environment Australia 2001).

Reviews of global wetland inventories and resources have been undertaken previously (Finlayson and Spiers 1999a; Finlayson et al. 1999), and a framework for development of a wetland inventory has been developed (Ramsar Convention Secretariat 2010b). These early reviews identified potential datasets, techniques and protocols for developing a comprehensive Australian wetland inventory and continue to be valuable (Paijmans et al. 1985; Pressey and Adam 1995; Finlayson and Spiers 1999b; Spiers and Finlayson 1999; Finlayson 1999; Kingsford et al. 2005). Nevertheless, the rapid advancement of new technology, mapping and data collection methods, and the potential for citizen science contributions, offer opportunities that warrant updating these earlier reviews.

This paper builds on previous reviews of wetland inventories (Dugan and Dugan 1990; Finlayson and Spiers 1999a; Finlayson 2003; Finlayson et al. 1999; Davidson and Finlayson 2007; Finlayson and van der Valk 1995) to include more recent information. It also presents a roadmap to implement a jurisdictional wetland inventory program. Application and relevancy of the roadmap is demonstrated by detailing a case study from NSW, Australia. Discussing the purpose, data requirements, approaches, accuracy and limitations of existing wetland inventories also provides an up to date understanding of the requirements and challenges relevant to building a national wetland inventory.

Generic roadmap for building a wetland inventory

A 'wetland inventory' can be defined as the collection and/or collation of core information for wetland management, including the provision of an information base for specific assessment and monitoring activities (Finlayson 1999, 2003; Ramsar Convention Secretariat 2010a). These include documenting the extent of all wetlands, or types of wetlands in a specific area; determining the location and attributes of wetlands of local, state, national and/or international importance; documenting the occurrence and distribution of wetland taxa or natural resources; and identifying baseline conditions for measuring change.

While there have been extensive reviews documenting the minimum requirements of a wetland inventory (Ramsar Convention Secretariat 2010b;

Finlayson and Spiers 1999b; Finlayson et al. 1999; Finlayson 1999; Kingsford et al. 2004), a generic roadmap for implementing a wetland inventory program has not previously been presented. This study develops and applies the roadmap to support inventory implementation. The roadmap is presented in Fig. 1 and includes six elements: identifying stakeholders and their requirements, establishing the governance structure, developing the project logic, scoping the technical aspects, executing the project, and developing the communication plan.

Identifying stakeholder requirements

The formal identification of stakeholders and their requirements for a wetland inventory is the first element of the process (Fig. 1), but in many projects, it is often underestimated or left too late. The intended multi-purpose use of a wetland inventory requires significant stakeholder engagement early in the development phase to identify end-user needs (Reed 2008; Phillipson et al. 2012; Hanak et al. 2013). Suggested key stakeholder groups include representatives from the government sector (Commonwealth, State and Local), research sector, community groups, and local landholders.

Stakeholder requirements can be determined through well-established International Association for Public Participation (IAP2) engagement processes (www.iap2.org); specifically, to inform, consult, involve and collaborate, where appropriate. Activities that can be used to engage stakeholders include participation in a project initiation workshop; online surveys; representation in the governance structure; and invitation to advise on the project logic, technical methodology or communication strategy (Fig. 1).

While stakeholder engagement is a continuous process, the first contribution sought from stakeholders is how they and their end-users intend to apply products or outputs from an inventory, and identify the environmental, social and economic (e.g., ecosystem services) information desired to facilitate end-user

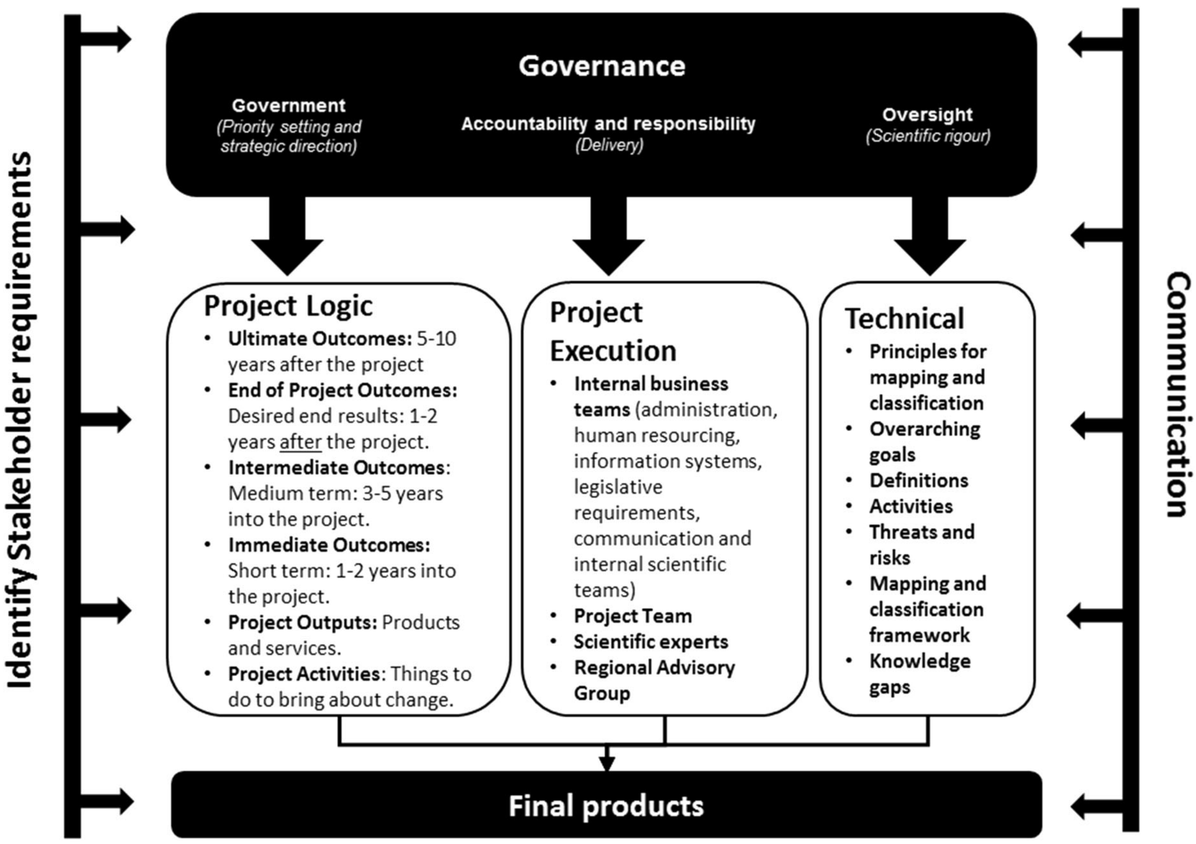


Fig. 1 Roadmap for implementing a jurisdictional wetland inventory program

uptake. This will focus development of the project logic. Initially stakeholders can also better understand the risk of a 'do nothing' approach and thus assist with management and mitigation of project risk.

Stakeholder inclusion from the project inception will build engagement, empower end-users, and manage expectations. A further benefit is that it develops networks of experts and cooperation for knowledge exchange.

Establishing the governance structure

The second element of the roadmap is the governance structure that drives program implementation (Fig. 1). It establishes the roles and responsibilities, enables organisations and individual stakeholders to commit resources (including expertise), and it fosters ownership of the process. Importantly, it assures stakeholders that key aspects of the project are recognised and that there is appropriate accountability. The suggested governance structure delivers on three functions: (i) setting of priorities and strategic direction; (ii) scientific oversight; and (iii) implementation oversight.

Priority setting and strategic direction

In the case of a jurisdictional wetland inventory the sponsoring organisation or government agency has primary carriage of this governance function. The governance group that sets the priorities and strategic direction of the program should include the representatives of high-level sponsors and executives in the agency and they oversee alignment of the project's strategic direction with agency priorities. They identify linkages to relevant internal information systems and stakeholders, as well as report on the value delivered to government and community. In doing so they monitor and assess feasibility, address major issues as they arise, track progress, identify any whole-of-government issues associated with the project and opportunities for strategic alignment, and ensure effort and expenditure are appropriate to stakeholder expectations. Members of this governance area promote the project and identify funding opportunities. An important tool that can be used to undertake the governance function of setting priorities and strategic direction is the project logic.

Project logic The project logic is a project management tool, commonly expressed as an infographic, which demonstrates how a program will deliver on penultimate goals through linking tasks and actions up through a cascade of short-term through to long-term deliverables and outcomes. It supports the narrative of the project, informs the plan, and strengthens the design by clarifying needs and whether new activities are required. Most importantly, it is developed through collaborative discussion between stakeholders, thus building relationships, ownership and understanding of the wetland inventory program, which will further encourage uptake of the final products. The project logic provides the organisational governance group reassurance that the program is aligned to corporate goals, and highlights they have the responsibility for its review and approval.

Scientific oversight

Another governance function is oversight of scientific rigour and technical aspects of the program. Commitment to scientific rigour throughout the program ensures that all science undertaken or commissioned meets globally accepted standards. The governance group that provides scientific oversight should include independent scientists from external government science agencies and/or academic research institutions. Inclusion of representatives from non-government (NGO) or not-for-profit (NFP) organisations is also recommended, as they often have high-level expertise, can advocate for the program, advise on user requirements, and provide local knowledge.

Further roles for the governance group providing scientific oversight are to provide guidance on scientific and technical issues, expert opinion to resolve technical issues, and advice on emerging technical opportunities. This governance group also identifies opportunities for strategic alignment beyond the lead government agency; and advises on approaches to promote, champion and identify funding opportunities. Without the scientific oversight function in the governance framework, a wetland inventory will potentially be judged as lacking scientific rigour with a major risk to the uptake of inventory products.

Technical approach The approach or technical framework provides guidance on the scientific and technical elements of the program, and includes a wetland definition, the mapping and classification principles, overarching goals and objectives, definitions, and scope of activities to address the objectives as well as the risks and threats. The approach is based on an agreed baseline developed through discussion with the experts and considers the relevance of the standard minimum requirements of a wetland inventory (Wilen and Bates 1995; Finlayson and Davidson 1999; Finlayson 1999). It also provides the rationale and methods for the accuracy assessment of mapping products, and integrates the most recent understanding and datasets for wetland mapping and classification systems.

Oversight of project execution

The third governance function is oversight of the project execution through an organisation's internal processes such as administration, human resourcing, information systems, legislative requirements, communication and scientific expertise. For example, the organisation's various science teams provide the specialist advice on access to spatial data systems, while organisational community and engagement specialists advise on best practices for disseminating project progress. Formal recognition of the various internal specialist teams can reduce barriers to staff contribution and participation.

A critical component of the implementation is review of the mapping and classification outputs by regional stakeholders. This has been shown to improve the project outputs and uptake through their endorsement (M. Ronan, Queensland Department Environment and Heritage Protection, *personal communication*).

Fostering communication

By fostering communication through the governance structure and activities, a communication strategy and plan is integrated into all elements of the roadmap. The strategy outlines the communication principles, the goals and objectives of the engagement, and core messages of the program. By recognising the key stakeholder groups, the development of the strategy and plan provides another activity to engage and build trust by reinforcing the programs commitment to engagement with end-users. It also opens the discussion on the potential to integrate organisational communication activities. A communication plan that is ideally a 'living' document that prioritises and focusses resources that create opportunities, and addresses the risks and threats. A short, yet comprehensive plan outlines the objectives that are actionable for the upcoming year. A timeline for regular reassessment allows further opportunity to foster stakeholder engagement.

Overall, the features of the roadmap (Fig. 1) provide a clear, transparent and open process to implement a wetland inventory program that is collaborative and inclusive. We suggest that addressing the six elements of the roadmap (identifying stakeholders and their requirements, establishing the governance structure, developing the project logic, scoping the technical aspects, executing the project, and developing the communication plan) will create opportunities and limit the project risks.

Case study: the Lachlan wetland inventory, a jurisdictional wetland inventory program

To demonstrate application of the above roadmap, we describe our experience from the NSW Office of Environment and Heritage's (OEH) pilot project focused on the Lachlan River Catchment New South Wales (NSW).

Lachlan River catchment, New South Wales Australia

The Lachlan River catchment boundary extends the length of the Lachlan River and includes its major tributaries (Abercrombie, Belubula and Boorowa Rivers, Mandagery Creek), associated uplands, slopes and floodplains. This area covers approximately 86,000 km^2, around 10% of NSW and 8% of the Murray-Darling Basin, and includes a diversity of biophysical landscapes and ecosystem types (Fig. 2). Flows in the Lachlan River are regulated by Wyangala Dam, Lake Cargelligo and Lake Brewster, with environmental water considerations managed under the Murray-Darling Basin Plan (Commonwealth of Australia 2012) and the Lachlan Water Sharing Plans (NSW OEH 2016a, b, c). There are several Directory of Important Wetlands in Australia (DIWA) listings for the Lachlan: Booligal Wetlands, Cuba Dam and

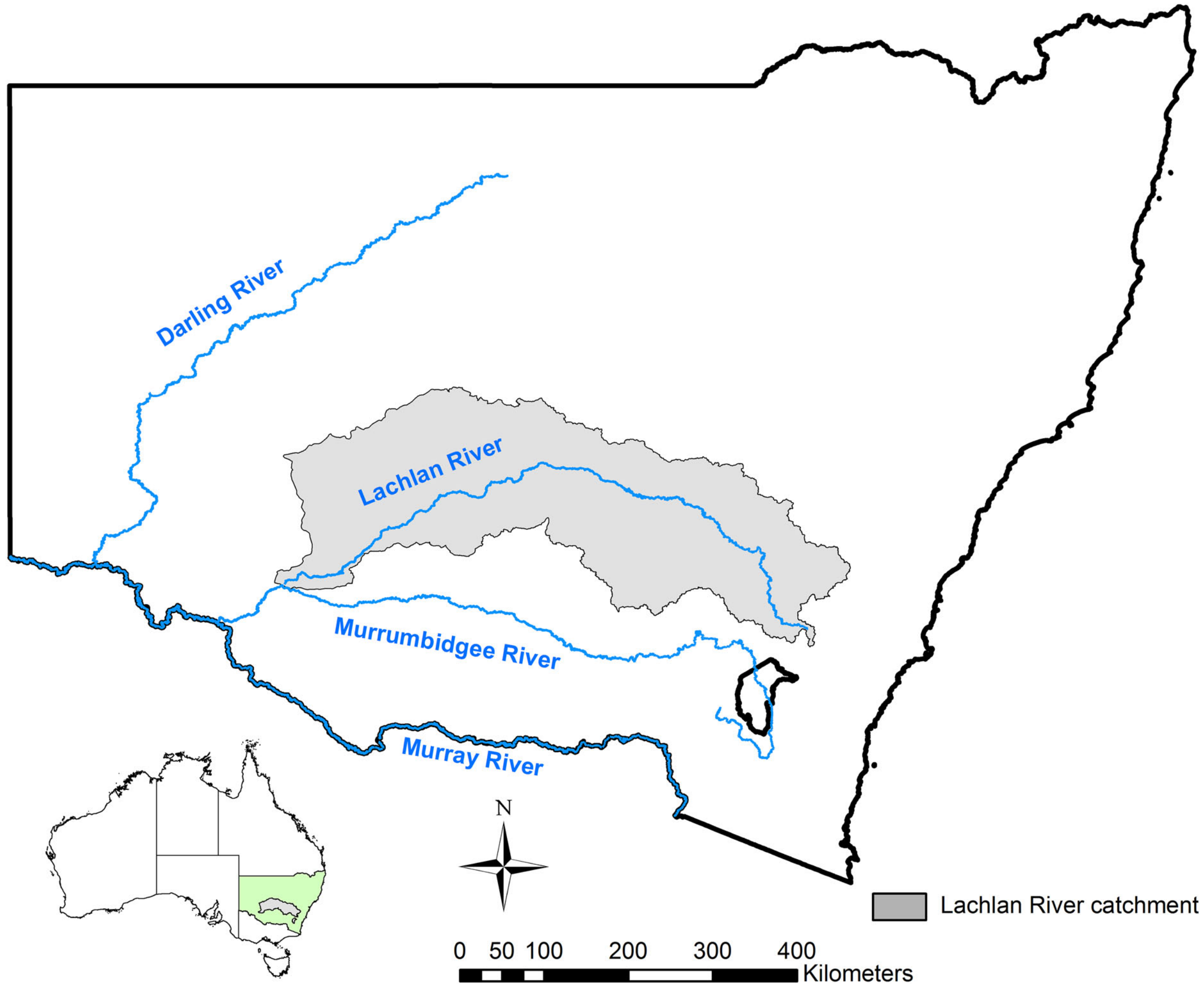


Fig. 2 Study area location of the Lachlan River catchment

Merrowie Creek, Great Cumbungi Swamp, Lachlan Swamp, Lake Brewster, Lake Cowal and Wilbertroy Wetlands, Lake Merrimajeel and Murrumbidgil Swamp (Environment Australia 2001). There are also 142 entities listed under the NSW Threatened Species Conservation Act, plus 5 species listed on the Commonwealth Environmental Protection and Biodiversity Conservation Act. Of the 142 NSW listings, there are 80 vulnerable species, 36 endangered species, 5 critically endangered species, 2 endangered populations and 10 endangered ecological communities.

Identifying our stakeholder requirements

To address the first element of the roadmap, a stakeholder workshop and confidential survey identified stakeholder requirements and their understanding of the knowledge gaps for a NSW wetland inventory (Powell and Ling 2014). Twenty-seven industry experts responded to the survey and 44 attended the workshop. These specialists represented government (Commonwealth, state, local government, councils), corporate (consultants and Sydney Water) and academic sectors (Table 1).

The recurring theme was the need for a consistent and comprehensive statewide wetland map or spatial layer and classification system for NSW as the essential components. They also identified the following issues to be addressed: improvement on the methods and data quality concerns of existing partial inventories; a revised spatial dataset of wetland extent across NSW, at a maximum of 1:25,000 scale to

Table 1 List of stakeholder groups represented at the initiation workshop in September 2014 to determine the requirements of a NSW wetland inventory

OEH	Other NSW government	Other government	Research institutions	Other
Science	Department of Primary Industry—Water	Queensland Department of Environment and Heritage Protection	*Macquarie University*	Sydney Water
Policy	Department of Primary Industry—Fisheries	Murray-Darling Basin Authority	*Sydney University*	*Consultants*
National Parks	*Royal Botanic Gardens and Herbarium*	Australian Government—Department of Water	*University of NSW*	*Wetland Care Australia*
Regional Operations and Heritage	Local Land Services	*Commonwealth Environmental Water Holder (CEWHO)*	*Canberra University*	
Business Information Systems	*Department of Planning*			
	NSW Department of Health			
	Local Councils			

Italics indicate representatives from organisations that were invited but not attend the Initiation–Stakeholder requirements workshop, and attended subsequent workshops in 2015–2017 to ensure their input into the process

capture small wetlands that have not been previously mapped; inclusion of vegetation community, hydrology, land use and tenure attributes; and a consistent and comprehensive wetland classification system aligned with national frameworks (ANAE, DIWA, Ramsar). A further requirement was that all data must be made discoverable and accessible to all potential users. Overall, all but one respondent agreed that there was a need for a revised statewide wetland inventory for NSW.

Respondents also indicated that a wetland inventory would benefit multiple purposes within their responsibility areas and their management of risk. In particular, those relating to (a) the management of wetlands (protection of key fish habitat, identification of biotic refugia, Ramsar, Environmental water, wetland plans of management), (b) planning (landuse, regional, local government reforms, water resourcing, construction of new wetlands for water quality treatment), (c) prioritisation of investment (to threatened species and biodiversity), (d) legislation and policy development (Sustainable Diversion Limit: SDL, Environmental Assets and Functions Information System: EAFIS, Northern Basin Review, Water Sharing Plans, Water Management Act, State Environment Planning Policy: SEPP, Biodiversity Conservation Act), (e) reporting (Monitoring Evaluation and Reporting: MER, State of the Environment: SOE, State of Catchment: SOC) and (f) communication with the public (awareness programs). From this initial enthusiasm, the NSW OEH funded a pilot project to scope the potential for delivering these various benefits from improved wetland knowledge, thus enabling and supporting further activities to better manage and protect wetlands across NSW.

To ensure continual engagement of stakeholders and end users, regular seminars, newsletters and internal social media platforms were used. These proved valuable in sourcing expertise in the development of the methodology, scoping the online delivery component, and creating networks and sparking new collaborations and ideas.

Governance

The development of the governance structure provided authority to the other elements. We established three levels of accountability that aligned with strategic leadership, scientific leadership and implementation. Terms of Reference (ToR) were developed at the inaugural meeting of each governance group to generate understanding, inclusion and engagement and shaped ongoing support. The approved governance structure included the project sponsor (OEH Executive Director of Science), and several groups to assist with strategic alignment, direction, and technical aspects of the project (Fig. 3).

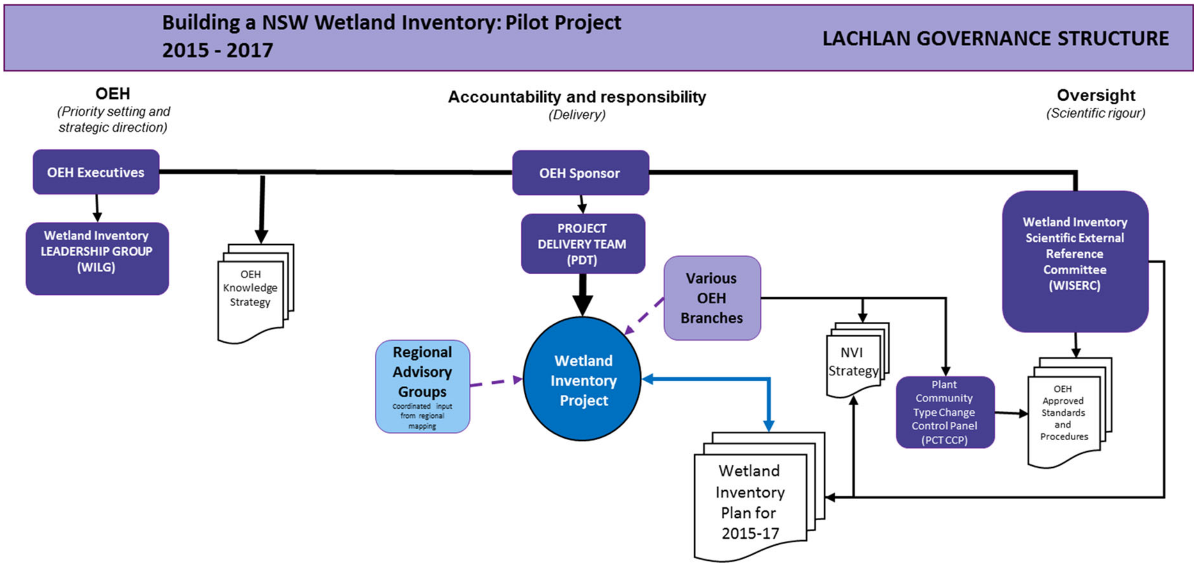


Fig. 3 Governance structure developed for building a wetland inventory in the Lachlan River catchment

Strategic leadership

The strategic leadership group—Wetland Inventory Leadership Group (WILG)—was responsible for strategic direction and priority setting. They approved major decisions regarding the direction, funding allocation and alignment of the project. Members included OEH Divisional Directors from Policy, Science, Regional Operations, National Parks and Business Information Systems. Along with the roles and activities listed (Generic roadmap for building a wetland inventory section), they reported on project progress to the OEH Executive and identified opportunities for strategic alignment within OEH and beyond. A key supporting program was OEH's Knowledge Strategy Program that aligns OEH science, research and knowledge management activities with legislative, policy and environmental management requirements (NSW OEH 2016b). A key benefit from this group was securing partnership funding.

Project logic process To ensure that the project priorities and strategic direction were aligned and approved by the WILG, we progressed a diagrammatic project logic through key stakeholders (Table 2, Online Appendix A). This was an independently facilitated activity aimed at obtaining input from managers and end-users, as well as other internal experts, to better understand the direction and goals of the project, and to ensure that their intent for the outputs were aligned.

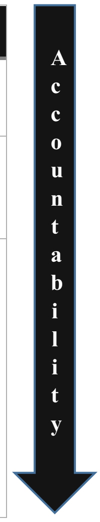
The long term Broader Goal was aligned with OEH's aspirations and business goals of supporting the Murray-Darling Basin Plan and 'ensuring vibrant natural assets for the health and prosperity of NSW' (NSW OEH 2017a). Specifically, to ensure that wetlands are maintained, protected and restored across NSW (Ultimate Outcome). Contributing to the achievement of this Ultimate Outcome (5–10 years after completion) requires subsidiary outcomes to be achieved including that: decisions on wetland management are based on reliable data and information, the inventory is used as a trusted source of information for wetland conservation and reporting; increased knowledge and understanding of wetlands is increased; research direction is informed; and comprehensive wetland data and information empowers communities to achieve wetland outcomes.

The End of Project Outcomes (end results 1–2 years after project completion) identify the immediate outcomes expected on completion of the project. They derive principally from the project deliverables and their immediate uptake by stakeholders and other end-users.

The Intermediate Outcomes (3–5 years into the project) included: all wetlands (above a certain size), in selected regions, are identified; representation of the

Table 2 The 'logic' or reasoning process for Building a NSW Wetland Inventory (see Online Appendix A for full project logic for Building a NSW Wetland Inventory)

GOALS	Time frames	Control
Broader goals	Project outcome deliver towards these in the long term	OEH's and broader-based aspirations.
Ultimate outcomes	5–10 years after the project	OEH and others have influence
End of project outcomes	Desired end results: 1–2 years after the project	
Intermediate outcomes	Medium term: 3–5 years into the project	OEH has control of these.
Immediate outcomes	Short term: 1–2 years into the project	
Project outputs	Products and services	
Project activities	Things to do to bring about change	



diversity of wetland types in NSW is understood; wetlands, in selected regions, are consistently mapped and classified; the wetland inventory is aligned with and informs other government policy, programs and planning; and increased number of partnerships established (Online Appendix A).

While none of the above outcomes were achievable for this two-year pilot project, most of the Immediate Outcomes were achieved: consistent and comprehensive data and information for wetland mapping and classification, conceptual models, classification scheme for wetlands that are aligned with existing systems are available, and datasets of core wetland attributes characterised.

While the 'Standard guidelines and frameworks for mapping and classification of wetlands' and data have been made publicly accessible through the OEH Data Portal (NSW OEH 2017c), the development of web-based delivery tools for wetland information was scoped and reported. With new developments within OEH Business Information Systems, the decision of the WILG was to postpone development and integrate with new OEH Spatial platforms as they became available.

Scientific leadership

The independent technical review panel of external partners from government and research institutions—Wetland Inventory Scientific Expert Reference Committee: WISERC—provided scientific oversight of the project. It was chaired by an OEH Science Director and Chair of the Water and Wetlands Knowledge Strategy (NSW OEH 2016b) with independent external partners representing government (NSW Department of Primary Industry—Water, Queensland Department of Environment and Heritage Protection), and academia (Macquarie University). In the second year (2016–2017), a non-government representative (Wetland Care Australia) was recognised as an omission and included on the panel. The WISERC were instrumental in providing guidance and reviewing the technical approach, clarifying technical issues, sourcing expertise and data, and refining the governance model. This proved valuable in assuring the WILG of the project's scientific rigour in terms of direction and strategy.

Technical approach The technical expertise of the WISERC and individual scientists was captured through the development of the mapping and classification framework. This consensus framework contained the purpose and principles for mapping and classification. The purpose was agreed to: improve on the previous statewide wetland map for NSW by improving on the accuracy and scale; build on existing classifications of wetlands and biodiversity information systems to better represent and provide information on the diversity of wetland types in NSW; and improve mapping and data to support regional to statewide approaches to wetland management and protection. The overarching goal of this module of the project was to produce a consistent map of wetland extent and type, with the underlying objectives that end-users have the information and data they need for evidence based decision making, and that knowledge gaps for NSW wetlands were identified and addressed. It was also essential to capture the scope of the project within clear boundaries by establishing principles for developing the methodology. Nine principles were agreed upon (Table 3).

The WISERC and technical experts also agreed upon the pragmatic definition of key terms (Table 4) including 'wetlands'. The agreed definition of wetlands (NSW Wetlands Policy: DECCW 2010) included wetlands fed by rainwater, rivers, groundwater and seawater.

The mapping and classification framework (Fig. 4) was used as a tool to communicate the approach undertaken by the project team. This framework specified the components required to identify wetland extent and classify wetland type to produce the wetland mapping. It also highlighted the need for accuracy assessment and review of the mapping by Regional Advisory Groups, as set out in the governance structure.

The classification component involved consideration of the Australia National Aquatic Ecosystems (ANAE) Classification Framework (AETG 2012), and in identifying suitable attributes to refine metrics for NSW. Accuracy assessment compared and evaluated environmental variables through statistical clustering. Once a typology was developed (Powell et al. *manuscript*), it could be aligned with other classifications such as vegetation systems.

Wetland Extent (Fig. 4) involved the development of extent and water regime from time series Landsat imagery and to include vegetation information from the State Vegetation Type Map: Central West/Lachlan Region (NSW OEH 2016c). The removal of errors was automated using ancillary spatial datasets by targeting potential errors using terrain models or air photo interpretation. Accuracy assessment used comparison of independent field surveys with mapped wetland boundaries, and was reviewed and evaluated by Regional Advisory Groups (RAG). The RAG included

Table 3 Principles for mapping and classification for building a NSW wetland inventory

	Principles for mapping and classification
1	Mapping methods will delineate wetland types consistently across NSW
2	The methods and classification will align with and extend the Australian National Aquatic Ecosystem (ANAE) framework for mapping and classification to ensure compatibility with Commonwealth wetland initiatives and also allow for flexibility to include information additional to that currently included in the ANAE framework. Mapping methods will also be compatible with wetland mapping programs in other states to avoid data compatibility issues across jurisdictional boundaries
3	Methods and the map product will build-on, support and align with existing OEH and other NSW Government programs as far as possible, including the NSW Native Vegetation Information Strategy, Environmental Water Management Program and the NSW Monitoring, Evaluation and Reporting Programs for Estuaries and Coastal Lakes, Rivers, and Groundwater. This will ensure that the project adds value to existing programs, avoids duplication of effort, creates efficiencies, and demonstrates responsible use of resources
4	The resulting spatial datasets will address the key knowledge gaps and provide information required by stakeholders, including supporting the development of variables to monitor wetland statewide wetland extent over time
5	Methods must be fit for purpose, robust and repeatable
6	Map products will be released with guidelines on their scale-appropriate use
7	All map products will be released with a date, version number and metadata statement, consistent with NSW standards. Revisions may be published with subsequent versions and dates
8	Data will be made accessible and publicly releasable
9	Mapping methods will be predominantly desk-top based, as resources for field surveys are limited. The focus of field survey data collection will be to support the calibration and accuracy assessment of the desktop mapping method

Table 4 Definitions and scope of wetland extent, wetland type, accuracy assessment and mapping scale as agreed through collaboration with technical working group representatives from the governance structure

Term	Agreed definition
Wetlands *NSW Wetlands policy* DECCW (2010)	"areas of land that are wet by surface water or groundwater, or both, for long enough periods that the plants and animals in them are adapted to, and depend on, moist conditions for at least part of their lifecycle. They include areas that are inundated cyclically, intermittently or permanently with fresh, brackish or saline water, which is generally still or slow moving. Examples of wetlands include lakes, lagoon estuaries, rivers, floodplains, swamps, bogs, billabongs, marshes, coral reefs and seagrass beds"
Wetland extent	The project will adopt the "maximum extent" through time and space approach to map wetland extent for wetlands that undergo wetting and drying cycles. This will include time series analysis of wetted areas, adopting water indices and ancillary datasets available through the imagery and remote sensing computing facility to include all wetlands present over the period for which we have a suitable Landsat archive (1987–2014)
	Not all wetland areas will be detected using Landsat imagery. Additional wetland areas will be identified using targeted approaches such as air photo interpretation, and use of existing fine scale vegetation mapping for small, mostly-wet, wetland types
Wetland type	Once wetland extent is determined wetland areas will be further subdivided to represent wetland types. GIS methods and existing maps of vegetation, landscape units and terrain will be used in combination with the water regime information from Landsat analyses to group wetlands into classes with shared characteristics
Accuracy assessment	Accuracy will be assessed by comparing the resulting wetland map with available independent ground survey data. We will produce a set of discrete multivariate statistics to measure the amount of agreement between independent ground-truthed dataset and the mapping dataset. This will include existing vegetation and soil survey data, and the collection of new field data to NSW standards. The results will be presented as error matrices. Error matrices will be included in the final report along with an interpretation and discussion of the results
Mapping scale	Previous statewide wetland map (2003) was produced at 1:250 000 for inland areas, as only Landsat Multispectral Scanner (MSS) imagery (80 m pixel size) was resourced for inland NSW at the time
	With new technology and innovation, it is anticipated a semi-automated method using archived Landsat imagery will detect water at a scale of around 1:50 000 (i.e., from Landsat thematic mapper imagery with pixel size of 30 m). Once the detection of water using the Landsat archive is completed, this study will further refine wetland boundaries by integrating higher resolution imagery and other spatial datasets
	The map scale resulting from the pilot study methods will be evaluated and described in the final report, and included in metadata statements accompanying the map product

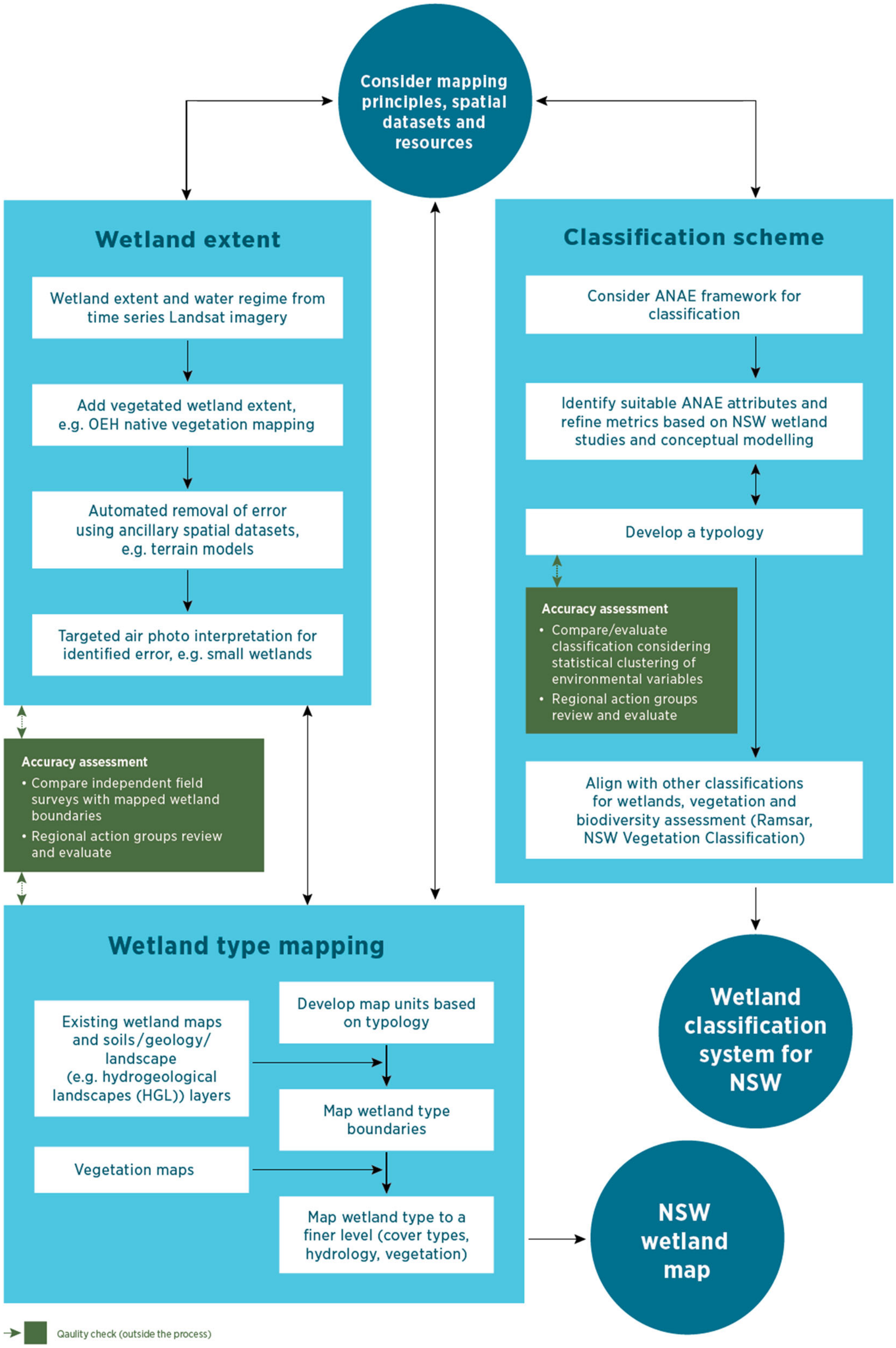
members of the Lachlan Environmental Watering Group (EWAG) and OEH Lachlan regional wetland managers, which includes indigenous representation. This engagement proved valuable and has led to the maps being used for various research projects in the Lachlan River catchment.

Implementation

In the first year of the project, the Project Delivery Team (PDT) members were a collaboration of organisational experts that provided access to the necessary breadth, and depth of expertise for technical, communication, human and technological information resources. In the project initiation phase the PDT and the WISERC, which was essential for endorsement and rigour of approach. As the project progressed and documentation was endorsed and organisational networks in place, the PDT was discontinued as a formal group. Individuals and teams were then contacted on a needs-by-needs basis when their specific expertise was required.

Communication strategy and plan

While the governance structure was the driving force, the communication strategy and plan provided the underlying foundation that sustained stakeholder buy-


Consider mapping principles, spatial datasets and resources
Wetland extent
Wetland extent and water regime from time series Landsat imagery
Add vegetated wetland extent, e.g. OEH native vegetation mapping
Automated removal of error using ancillary spatial datasets, e.g. terrain models
Targeted air photo interpretation for identified error, e.g. small wetlands
Accuracy assessment
• Compare independent field surveys with mapped wetland boundaries
• Regional action groups review and evaluate
Classification scheme
Consider ANAE framework for classification
Identify suitable ANAE attributes and refine metrics based on NSW wetland studies and conceptual modelling
Develop a typology
Accuracy assessment
• Compare/evaluate classification considering statistical clustering of environmental variables
• Regional action groups review and evaluate
Align with other classifications for wetlands, vegetation and biodiversity assessment (Ramsar, NSW Vegetation Classification)
Wetland type mapping
Existing wetland maps and soils/geology/landscape (e.g. hydrogeological landscapes (HGL)) layers
Vegetation maps
Develop map units based on typology
Map wetland type boundaries
Map wetland type to a finer level (cover types, hydrology, vegetation)
Wetland classification system for NSW
NSW wetland map
Qaulity check (outside the process)

◀ **Fig. 4** Mapping and classification framework was developed to communicate the mapping and classification approach

in and engagement throughout the pilot project. The activity outputs from the Communication Plan included OEH webpages and newsletters (NSW OEH 2017b), internal and external workshops and presentations including to the Lachlan Environmental Water Advisory Group (EWAG), World Wetland Day activities, and conference events.

Both the strategy and the 'living' plan were developed with OEH communication officers. Documentation focused on the foundation and communication principles, the core messages, identification of key stakeholder groups, the goals and objectives of the engagement, the overarching communication activities to address the engagement objectives, as well as the engagement risks and threats. The principles aligned with the OEH Engagement Principles that: our engagement is fit for purpose, we are open and transparent; we actively seek input from a range of sources; we are inclusive; and we listen, and learn from the past. The core messages focussed on the key stakeholder groups and included phrases such as: this project is about collaborating and actively encouraging expert input from a range of sources; this project will be scientifically rigorous; this project will abide by the principles of Open Government/Open OEH; this project will produce high quality data and information; data and products will be easily accessible to those who need it; and this project will assist in ensuring evidence based decisions making.

We undertook communication activities to establish strategic alignment, governance structures, and processes that would be approved by the governance groups. Collaboration and engagement were key principles of the project implementation. All the above processes (project logic, communication plans, mapping and classification methodology framework) were key activities to facilitate two-way dialogue to build relationships and engagement. For example, the project logic process was aimed at managers and end-users to better understand the direction and goals of the project, and to ensure that their intent for the outputs were aligned. To facilitate the more technical end-users, considerable time and discussion was allocated to establishing the methods and framework for mapping. As in all truly collaborative programs, the first year of the communication plan was especially resource heavy to promote ownership and end-user uptake. The second year's resources were directed to the technical component of the project, with a more targeted communication plan with stakeholders from the Lachlan River catchment.

Knowledge gaps and review

A key requirement of the stakeholder workshop was a thorough understanding of existing datasets for potential inclusion into a NSW wetland inventory. Through the various governance groups, we documented many existing national, state, regional and local scale wetland datasets with their purpose, data requirements, and limitations for application to a NSW inventory (Table 5, Online Appendix B).

The 'Kingsford Layer' mapping (Kingsford et al. 2003, 2004; Nairn and Kingsford 2012) represented the first significant attempt at a statewide inventory of wetlands in NSW. It is currently integrated into environmental water allocation, water sharing and long-term watering plans, Ramsar and DIWA nominations and the National Reserve System. Increasingly, however, wetland managers and scientists find that its focus on larger inland wetlands does not provide them with the information they require for decision making, particularly with the greater understanding of the value and vulnerability of small wetlands (Gibbs 1993; Semlitsch and Bodie 1998; Hughes 2011; Hope et al. 2012). Many of these are listed as national and state level threatened ecological communities or recognised as providing habitat for threatened flora and fauna. Since 2003, potential mapping methods have rapidly advanced with new remote sensing technology and greater computing power.

More recent datasets allow for increased spatial data coverage and resolution (Davidson and Finlayson 2007; Rosenqvist et al. 2007; Rebelo et al. 2009; Zomer et al. 2009; ABARES 2011) and methods have been refined to more accurately map water bodies, inundated areas, and inundated vegetation (Rundquist et al. 2009; Adam et al. 2010; Thomas et al. 2015). For example, inundation indices have been formulated for open water (Geoscience Australia 2014; Mueller et al. 2016) as well as for inundated vegetation (Thomas et al. 2015). With the recent arrival of high-resolution

Table 5 List of wetland inventories resources in NSW, and other states for potential inclusion of data into a NSW wetland inventory

Wetland inventory resources		
New South Wales	Other Australian states	Other Australian
NSW wetland layer Kingsford et al. (2003) and (2004) Nairn and Kingsford (2012)	Queensland Wetland Info QEHP (2005) https://wetlandinfo.ehp.qld.gov.au/wetlands/	Directory of Important Wetlands of Australia (DIWA) Environment Australia (2001)
NSW State Environmental Planning Policy (SEPP) Adam et al. (1985)	Victoria VDEPI https://www.water.vic.gov.au/waterways-and-catchments/rivers-estuaries-and-waterways/wetlands	MDB ANAE Murray-Darling Basin (MDB) regional mapping Brooks et al. (2014)
NSW Estuary Inventory Roper et al. (2011) NSW OEH (2013) http://data.environment.nsw.gov.au/dataset/an-estuarine-inventory-for-new-south-wales-australia-vis_id-22246f1a4	Tasmanian Tasmanian Government 2014 http://dpipwe.tas.gov.au/water/water-monitoring-and-assessment/cfev-program	CSIRO's (Commonwealth Scientific and Industrial Research Organisation) MDB Aquatic Ecosystem Mapping and Classification Project (The Cluster) Bunn et al. (2014a, b)
WISE database https://www.ecosystem.unsw.edu.au/content/conservation-practice/information-management/wise	Western Australia Government of Western Australia (2017)	
	South Australia: South Australian Wetland Inventory Database (SAWID) Government of South Australia (2014) https://www.environment.sa.gov.au/Science/Science_research/Seascapes_landscapes_and_communities/Ecological_community_mapping/Wetland_inventories_and_mapping	
	Northern Territory Duguid et al. (2005)	

See Online Appendix B for a summary noting the purpose and brief description, compliance to minimum and additional data requirements (Finlayson 1999) and limitations for use in a revised inventory for NSW

This project received funding from the NSW Office of Environment and Heritage

climate change projections (e.g. NSW and ACT regional climate modelling (NARCliM) Project; Olson et al. 2014), hydrological impact assessments of potential change in surface flow and groundwater recharge have become possible and have already been developed for NSW (Vaze et al. 2008, 2013; Littleboy et al. 2015). These can be used to determine current trends and future annual and seasonal changes to wetland water sources, and are currently being used to develop and undertake wetland climate change vulnerability assessments (Cowood 2016). Further environmental impact assessments based on the NARCliM climate change projections could be used to attribute wetland pressures and trends.

Further regional and local inventories for NSW are also relevant (Young et al. 1996; Budge 1998; Webster and Davidson 2003; Ecological Engineering 2005; Burns et al. 2006; Hale et al. 2006; DECCW 2011; Wetland Care Australia 2014). These local inventories (not listed in Table 5), although restricted in extent, are usually undertaken at a finer spatial scale and are considered data rich, where logistics are suitable for research towards defining subtle variation important to the wetland diversity in that location.

Other Australian states have several wetland mapping programs that are in various stages of completion that could contribute to an Australian wetland inventory (Table 5).

Final Lachlan River catchment wetland map

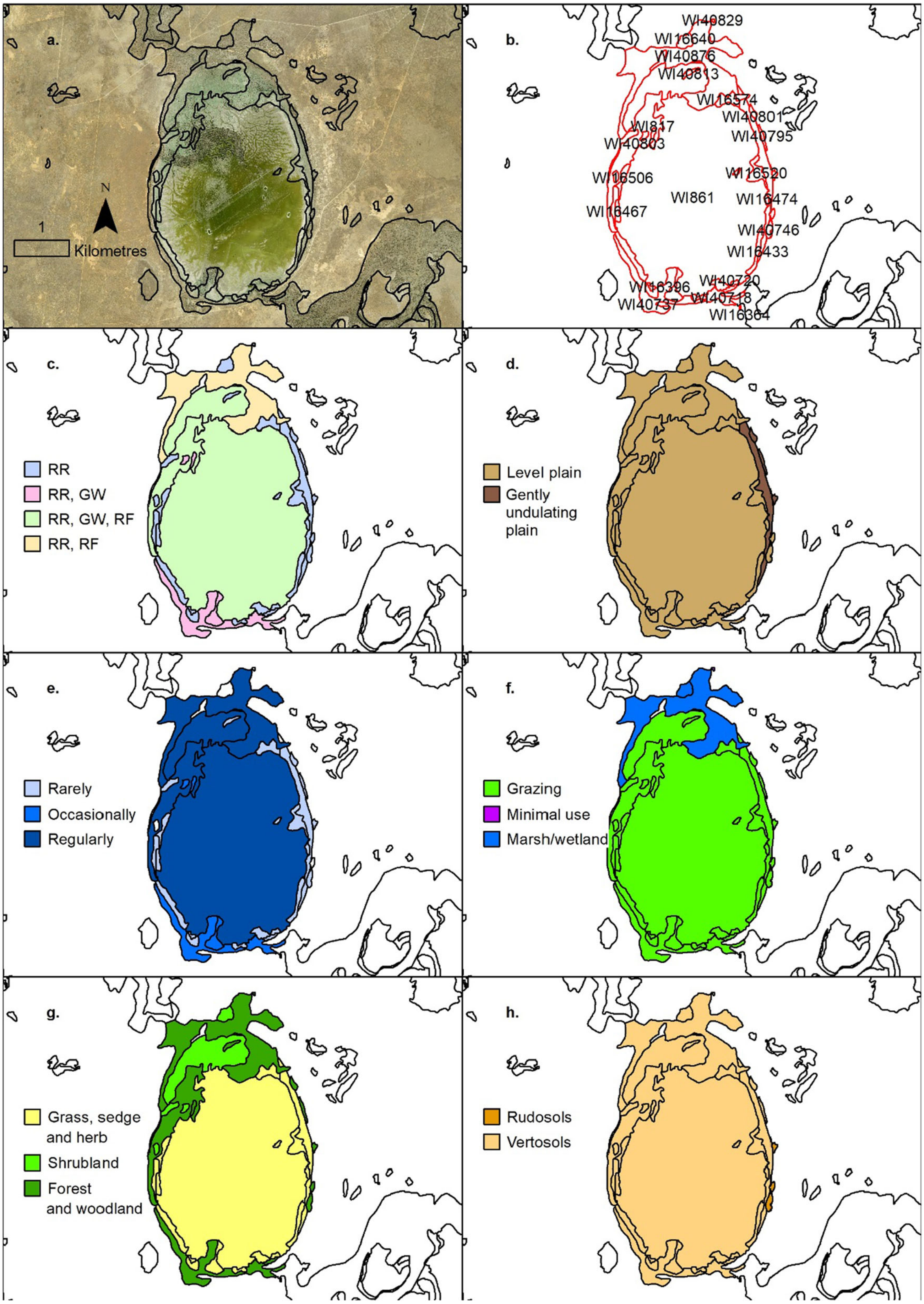
The final wetland map of the Lachlan River catchment was progressed through the development of semi-automated techniques to rapidly generate inundation histories (a key-driver for wetlands) over large arid and semi-arid areas (Ling et al. 2017). Map boundaries were delineated using remote sensing datasets, existing vegetation mapping, and object based image analysis tools. Other products produced for the Lachlan that can be integrated directly into a statewide or national inventory include historical (30-years) inundation history 'fingerprints' (Ling et al. 2017), data on wetland percent inundated for each Landsat capture, plant community profiles, and a wetland plant indicator list (Ling et al. *accepted*). Attribution of the wetland maps was achieved by generating new datasets from remote sensing and GIS methods, as well as by integrating existing datasets. Final attribution included wetland identification number, soil, water source, geomorphic position, vegetation structure, inundation class, and land use (Powell et al. 2017) as shown in the Fig. 5 example for Lake Ita. Datasets have been made publicly available (NSW OEH 2017b, c), and publication of results are currently in progress. The outputs and methods are already in use to support various OEH priorities and external partners including Ramsar, Ecological thinning programs, and floodplain vegetation research in the Lachlan.

Challenges for building a jurisdictional wetland inventory program

By completing a pilot project in the Lachlan River catchment, NSW OEH have further progressed a revised statewide wetland inventory. This project has highlighted the need for a clear program with inbuilt engagement and awareness aspects, and drawn attention to the current lack of comprehensive data and information required for legislative and operational management of wetlands in NSW. It has also highlighted the need not only for a statewide wetland inventory but a coordinated national inventory. One of the first barriers to developing a wetland inventory is the lack of understanding of the requirements for initiating the program. The pilot project in the Lachlan region applies the roadmap and demonstrates the possibility for others to initiate and progress a program of stakeholder engagement and communication that is inclusive of higher level executives and managers, as well as operational and technical experts. This roadmap generates the foundation for future relationships and understanding of the challenges and creates ownership of the outcomes and outputs.

Government priorities and timing of funding opportunities precluded progression of the mapping and classification component in 2017–2018. One of the greatest challenges to securing long-term funding for a wetland inventory is a widespread expectation that such fundamental information should already exist and its ongoing funding supported by government. Another challenge is staff retention and continuity of capability and expertise when funding is sporadic. A nationwide dialogue for the integrated conservation and wise use of wetlands, starting with a comprehensive stocktake of the extent, location and type of wetland asset, would initiate commitment to understanding this critical resource.

Major limiting factors for many inventories noted in early reviews (Finlayson and Spiers 1999a, b; Finlayson et al. 1999; Kingsford et al. 2003, 2004, Kingsford et al. 2005) were insufficient data availability, coverage and resolution (Finlayson 1999). Regrettably this is still true, albeit to a lesser extent, and notably in NSW. We found that while wetland mapping is seemingly available for significant areas of NSW, compilation of existing maps is difficult due to the differences of scale, coverage, wetland definitions, typologies and methods. Consequently, the accuracy and precision of the resulting compilation map is difficult to quantify uniformly and thus unsuitable as a comprehensive wetland map for NSW. Wetland managers and scientists acknowledge there are significant gaps in understanding of wetland location, extent and diversity required for decision making. By capitalising on a combination of significant advances in technology (computing power, improved spatial science techniques, a dramatic increase in the availability of satellite and airborne imagery), and



a.
N
1
Kilometres
b.
WI40829
WI16640
WI40876
WI40813
WI16574
WI40801
WI817
WI40795
WI40803
WI16520
WI16506
WI861
WI16474
WI16467
WI40746
WI16433
WI40720
WI16396
WI40718
WI40737
WI16364
c.
RR
RR, GW
RR, GW, RF
RR, RF
d.
Level plain
Gently undulating plain
e.
Rarely
Occasionally
Regularly
f.
Grazing
Minimal use
Marsh/wetland
g.
Grass, sedge and herb
Shrubland
Forest and woodland
h.
Rudosols
Vertosols

◀**Fig. 5** An example the final product for Lake Ita including an aerial map, and attributes of wetland identification number, water source, geomorphic position, inundation regime, land use, soil and vegetation structure. Water source codes: *RR* rainfall/runoff, *GW* groundwater, *RF* river fed

improved understanding of wetland types, we have explored improving methods for wetland mapping. These techniques are increasingly more quantitative rather than subjective interpretations of the landscape, and importantly, offer increased opportunities for automation.

In NSW, the development of the Imagery and Remote Sensing (IRS) facility permits rapid and repeatable processing of very large spatial areas. It also includes the full Landsat archive. This facility has automated and pre-processed analyses, such as atmospheric corrections, and applied them to the Landsat archive. This has provided the opportunity for new techniques to be automated and applied as they become relevant, allowing a greater focus on the development and understanding of remote sensing techniques for land cover analyses such as wetland mapping. However, with new methods come new challenges to test, and the inherent problems associated with identifying boundaries in dynamic ecosystems and through wet and dry phases such as occur in inland NSW (Powell et al. 2017).

An integrated classification or typology system requires that all jurisdictions are aligned with a national framework. The Australian National Aquatic Ecosystem (ANAE) Classification Framework developed by a multi-jurisdictional Aquatic Ecosystems Task Group (AETG 2012), has enabled Queensland and Victoria to align their systems and therefore can be easily integrated into a national wetland inventory. Attempts to develop these in the Murray-Darling Basin (Brooks et al. 2014) note that data is not comprehensively available with the required level of detail for some jurisdictions. The ANAE framework is a 'top down' (rules-based) approach to classification that includes provision to include both surface and subterranean aquatic ecosystems (Butcher et al. 2011). However, the rules-based approach is not the only approach for grouping wetlands with 'bottom-up' statistical approaches also being developed (Turak and Koop 2008; Bunn et al. 2014b; Tierney et al. 2015; Timms and Boulton 2001). We suspect that using a combination of approaches—top down with statistical validation from the bottom up—will provide the transparency, consistency and statistical detail required. We are currently testing this with the Lachlan Wetland Inventory (working manuscript).

Building a national wetland inventory is not anticipated to be a one-off process but constantly evolving. There is the need for the spatial mapping and attribute dataset to be periodically reviewed, evaluated and updated. The inventory should have the scope to make use of recent advances in methods and newly available datasets to develop new data products to meet the needs of stakeholders and end users, while integrating all states data and information.

Review, evaluation and updating procedures should establish whether the inventory is still meeting its original purpose and objectives, along with recommendations for improvement (Finlayson 1999; DECCW 2010; Ramsar Convention Secretariat 2010b). Keeping a wetland inventory current is vital to facilitate assessment, management, monitoring, policy and decision making by stakeholders (Green 1997; Bedford 1999; Finlayson et al. 1999; Innis et al. 2000; Finlayson 2003; QEHP 2005; Kingsford et al. 2005; Ling 2010; Ramsar Convention Secretariat 2010a, b; DERM 2011a, b; Turak et al. 2011; AETG 2012). These updates will allow for continued evidence-based government decision making, monitoring and evaluation, filling data gaps and method advancements.

With the rapid advancement of technology and online accessibility, one tool to assist in this process would be a spatially enabled 'virtual' (digital and online) wetland inventory that integrates all data and information as well as allowing public access to the data and information. This would ensure that wetland data and information is discoverable, accessible and reliable from a single point source, and can be updated/added to ensure longevity. Ideally, this would include a spatially enabled platform to include not only links to spatial data, but also reports, documents, scientific papers, photos and videos, and citizen science inputs that can be uploaded. Currently, OEH data is uploaded onto the OEH Data Portal, which will progressively be incorporated into the NSW SEED (Sharing and Enabling Environmental Data) Portal (NSW Government 2017) over time. Public access to the inventory will promote education and awareness of wetland ecosystems. The inventory will also assist with public confidence and support for government decision making processes related to water use, wetlands, and the amelioration of threats.

The challenges for wetland management are evolving, and some argue that the concerns are 'wicked' problems where there is no agreement on the nature of the cause (Rittel and Webber 1973; Colebatch 2006). The consequences of management actions are uncertain (Allan 2008), involve players from many disciplines and knowledge (Ludwig 2001), solutions are seen as good and bad by stakeholders, and where the problem can be seen as a symptom of another problem and thus its existence can be explained in numerous ways (Rittel and Webber 1973; Head 2008). One of the key steps, it is argued, for managing 'wicked' problems requires an integrated and collaborative approach (Freeman 2000; Colebatch 2006). A jurisdictional wetland inventory developed using the roadmap described here, involving the commitment and unified efforts of stakeholders both inside and outside of government, supports such an approach.

The role of Best Available Science (BAS) is to provide a key element in decision-making and an acknowledgement that it is the best science available, not the best science possible (Ryder et al. 2010). Once this is established, evaluating wetland change can be managed within an adaptive approach (Allan 2008; Allan and Stankey 2009) to enable multidisciplinary teams to incorporate new knowledge and identify new uncertainties, limitations and inconsistencies and revisions. Collaborative understanding of stakeholder requirements or knowledge needs can be incorporated early in the process, as well as clear goals through the project logic process to ensure strategic implementation and integration. Developing effective communication strategies through peer-reviewed literature, reports or other formats as preferred by the management and policy audience are essential for knowledge exchange beyond the stakeholders (Ryder et al. 2010).

Development of a National Wetland Inventory for Australia has the potential to ensure Australian aquatic ecosystems can be better maintained and managed. To move forward, ecosystem-based management should be approached through adaptive management, allowing flexibility and inclusiveness to deal with constant environmental, societal, and political change (Slocombe 1998). Wetland inventory frameworks set out minimum requirements in terms of datasets and attributes, with a national framework for grouping wetlands considered a standard. With Queensland, Victoria and the Murray-Darling Basin already having data and information aligned to a national framework, other jurisdictions can develop their mapping and typologies, ready to be integrated. However, there is no standard for mapping wetlands (Kingsford et al. 2005), and with the rapidly changing advances in technology, this will be unlikely and so the capability for revision and updating must be inherent in the development and delivery process. The ability to deliver information via spatial interfaces allows for a 'virtual' (digital and online) wetland inventory, with 'live' access to the most recent data through open data portals.

Pressey and Adam (1995) identified the legislative and jurisdictional frameworks in place between the States and Territories as a key challenge precluding development of a comprehensive national inventory, and this challenge persists today. The fragmentation of jurisdiction and administration powers has been documented as a major barrier in taking a holistic view of ecological phenomenon, particularly in wetlands (Shine and de Klemm 1999). Such barriers may be territorial (relating to geographical boundaries of administration), or functional (relating to the subject matter over which the administrative body concerned has jurisdiction). Wetland flora and fauna in NSW, as an example, fall under International (Ramsar, IUCN Red lists, migratory bird agreements), national (Environmental Protection Biodiversity Conservation Act: EPBC Act), and numerous state legislation (e.g., Threatened Species Act 1995, Fisheries Management Act 1994, Biodiversity Conservation Act. Water Management Act 2000). In coastal zones, there are even more complicated administrative obstacles with the marine/terrestrial jurisdictional split deeply embedded in policy and administrative tradition and practice (Shine and de Klemm 1999). In NSW, there are multiple government agencies that are accountable for wetlands. State government departments with administrative jurisdiction over water, environmental conservation, fisheries, state forests, planning; and local government agencies including local councils and catchment authorities that have local administrative jurisdiction over local planning and conservation. Other challenges such as funding, development and maintenance of the online inventory, updating 'live' data, and incorporating public feedback and inclusion, and political will cannot be resolved easily.

Nationwide dialogue based on collaboration and coordination (horizontal and vertical) is the first step to initiate overcoming barriers in jurisdiction, methods and resources, especially in the context of environmental change which are especially affecting our wetlands. At the national level coordination, we strongly recommend the inclusion of facilitators that can bridge the science-policy nexus to be included for effective knowledge exchange between the different cultures of discipline (i.e., language, reward systems, timeframes) (Briggs 2006; Borowski and Hare 2007; Ryder et al. 2010). While outside the scope of this paper, there is extensive literature on the "turbulent boundary" (Cullen 1990) between water science and management, and the need to address the dysfunction at this critical nexus (e.g., Cullen 1990; Benda et al. 2002).

Once a national wetland database is established the involvement of citizen science programs could be better integrated to assist in monitoring change in these aquatic ecosystems. The involvement of volunteers in research has increased the scale of ecological field studies with continent-wide, centralized monitoring efforts and, more rarely, tapping of volunteers to conduct large, coordinated, field experiments. While we recognise that citizen-science produces large, longitudinal data sets, the potential for error and bias is poorly understood and is best viewed as complementary to more localized, hypothesis-driven research (Dickinson et al. 2010).

To build a nationally aligned wetland inventory in Australia, a consistent and comprehensive mapping and typology of wetlands are the key first components. That is, the first objectives of a wetland inventory program are to: identify and address knowledge gaps on the extent and type of wetlands; provide a comprehensive spatial and attribute dataset; and develop guidelines for consistent and repeatable data collection. Other objectives such as addressing government wetland accountability and enabling public access to wetland information should also be included. The roadmap presented herein will support achieving these objectives.

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